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Factors Influencing the Adoption of Timber Bridges (Literature Review)

The Role of New Technology Adoption in the Timber Bridge Market: Special Project Fiscal Year 1992

PREFACE

This publication is a technology transfer effort by the USDA Forest Service, Timber Bridge Information Resource Center, in cooperation with the Center for Forest Products Marketing, Department of Wood Science and Forest Products, at Virginia Polytechnic Institute and State University, under a grant from the USDA Forest Service.

This publication provides the background, justification, and states the objectives for the development of a five-part marketing analysis of timber bridges.

This is Part I; a literature review of technological advances in modern timber bridges, perceptions of decision makers, and those marketing factors which influence timber bridges in the marketing arena. It describes the industrial innovation process and barriers to the adoption of new products. It concludes with a discussion of the decision-making processes and the Analytical Hierarchy Process.

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Other publications in this five-part series are:

A Perceptional Investigation into the Adoption of Timber Bridges, NA-TP-03-95 (Part II)
A Hierarchical Analysis of Bridge Decision Makers, NA-TP-04-95 (Part III)
Marketing Practices in the Timber Bridge Industry: 1993, NA-TP-05-95 (Part IV)
A Strategic Evaluation of Factors Affecting the Adoption of Timber Bridges, NA-TP-06-95 (Part V)

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Timber Bridge Information Resource Center

TECHNOLOGY
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The Role of New Technology Adoption in the Timber Bridge Market: Special Project Fiscal Year 1992

Factors Influencing the Adoption of Timber Bridges

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BACKGROUND

Technological advances during the past decade have allowed under-utilized species and lower-grade lumber to be used in modern timber bridges. However, the adoption rate has been slow and uneven throughout the United States. Although engineers have proven that timber can be designed into bridge components, perceptions by decision makers remain one of the main barriers to adoption of this new technology. With a thorough understanding of such barriers and decision-making processes, further adoption of this technology can be enhanced.

In recent years, the need for bridge replacement has been well documented. An estimated 220,000 (41%) of our nation's bridges are deficient. The cost of replacing deficient bridges exceeded $51 billion dollars in 1988 (USGAO 1988). In 1991, more than 4,400 bridges were repaired or replaced at a cost of over $4 billion (Highway and Heavy Construction 1991). This represents an opportunity for the timber industry to serve a market niche with bridges utilizing less desirable and lower grade species.

It was recognized in the late 1980's that modern timber bridges could help repair the infrastructure of the United States, and at the same time, help revitalize rural economies. By utilizing local species and labor, rural bridge replacement and unemployment problems could be addressed.

With the assistance of the USDA Forest Service and other research institutions, the United States Congress passed funding for the National Timber Bridge Initiative starting in fiscal year 1989. The major components of the initiative include research, demonstration bridge construction, and technology transfer. Through 1993, the initiative has resulted in the funding of 272 demonstration timber bridges in 48 states (USDA 1993). However, adoption has been uneven, with many demonstration bridges, about 30%, being built in only 2 states: Pennsylvania and West Virginia.

Timber has been used for bridge construction since the beginning of our country. It has evolved from the simple log stringer to sawn timber, bolted connections, treated wood, glue-lam stringers, and now to pre-stressed timber. All of these improvements were a result of advances in technology. For a while, it renewed interest in timber as a bridge material. However, that short-term interest was ultimately lost as superior competing products entered the market. Popper and Buskirk (1992) state that marketing of traditional products must keep pace as the products evolve through the technological life cycle. The limited success of timber bridge adoption in this century suggests that ineffective marketing efforts may be a primary reason that interest in these bridges has waned.

Although the current technology push exhibited by the Forest Service has led to wider use of timber for bridge construction, the success of this product will ultimately rest upon marketplace acceptance. The uneven adoption rate exhibited to this point indicates that negative perceptions of timber bridges may represent a barrier to adoption.

The three major facilitators for adoption of new products are:

- Marketing and managerial synergy
- Strength of marketing communication and launch efforts
- Market need, growth, and size (Cooper 1979)

These three factors are all market oriented. Successful introduction of innovative products depends on a thorough understanding of the market and customer needs.

Efforts to understand barriers of entry for new products have been primarily focused on competitive responses, not marketplace acceptance. Barriers to entry are anything that decreases the likelihood, scope, or speed of potential competitors coming into the market (Shepherd 1972). They can be viewed as features of an industry that give incumbents inherent advantages over potential entrants (Porter 1980). The organizational adoption process is complex, and frequently not well understood by managers. As a result, many barriers to the adoption of a technical innovation are unseen, unanticipated, and unmanaged (More 1986). This ends with the rejection of many apparently technologically superior products by potential buyers.

The six major classes of barriers include:

- Economies of scale
- Product differentiation
- Absolute cost
- Access to distribution
- Capital requirements
- Incumbent reaction (Yip 1982)

No recent studies have indicated that customers have inherent beliefs not to try a new product. Of the six major barriers, only incumbent reaction takes into consideration the customer's perception of the new product. The other five barriers are competitive features within a given industry. Yet, it is the customer's perception of the product that will lead to the formation of an attitude, which will ultimately result in a purchase decision.

Currently, the concrete and steel industries hold more than a 90% share of the bridge market in the United States (Dunker, Klaiber, and Sanders 1987). Between 1983 and 1986, the number of timber bridges in the United States declined by over 13% to a total of 60,500 (Cundy 1989). It is evident that decision makers throughout this country have negative perceptions of timber as a construction material for bridges.

The goals of this research were:

- To identify positive and negative perceptions that exist concerning the use of timber in bridge construction
- To determine the most important non-structural material attributes in the bridge design decision

This was accomplished by surveying design engineers in 28 states. Case studies were conducted in four geographically selected states: Mississippi, Virginia, Washington, and Wisconsin. These case studies were supported with a mail questionnaire to decision makers in neighboring states.

Cooper (1979, p. 101) states:

> *"The commercial viability of a new product rests in the hands of its potential customers; and therefore a solid understanding of the marketplace together with an effective market launch effort is vital to new product success."*

The launch effort by the Timber Bridge Initiative has been quite successful in bringing this new technology to the rural countryside.

Moody, Ritter, and GangaRao (1990, p. 423) state:

> *"As a result of the Timber Bridge Initiative, research on material properties, preservative treatments and system development has significantly expanded in the past two years. Most of this research has addressed the development of new bridge systems with an emphasis on hardwoods, which are currently under-utilized for structural applications."*

However, in the rural political arena, there is a current lack of understanding of the marketplace and decision-making processes involved with the purchase of timber bridges.

As with many industrial products, the timber bridge is a large capital expenditure in which the purchase decision is done by a group. Many levels of government may be involved with this decision and each level may have perceptions and attitudes concerning the use of timber. Numerous factors inhibit and promote change from a pre-existing product or pattern of behaviors.

Ellen et al. (1991) identify some of these factors:

- Environmental factors
- Perceptions of change-promoting agents
- Degree of tolerance for risks and costs
- Loss of autonomy or control

These authors go on to say that humans or organizations tend to avoid change by favoring the current situation or status quo unless an alternative is presented which is excessively attractive or very pressuring. Decision making tends to be based on previous solutions and past success unless these are no longer viable. Current bridge decision makers are trained and familiar with concrete and steel as a bridge material. The adoption rate of timber bridges to this point indicates that the decision makers are not ready to re-try timber as a permanent solution for bridge replacement.

The modern stress laminated timber bridge can be considered a significant product innovation. With marketing in mind, Brown (1992, p. 41) states:

> *"An innovation can be defined as a new product, process or system which has the potential to create an entirely new market, or change an existing one in a way which creates new patterns of competitive or customer behavior. The point in marketing terms being that the customer should perceive it to be novel. The power of innovation to create new markets and competitive advantages underlies its significance in strategic marketing management."*

This makes the literature concerning the adoption of innovation and the industrial decision-making process quite relevant to this study. This literature identifies several types of barriers to new product innovation, with lack of market research being a primary one. This study will investigate these barriers so that they can be better understood and overcome.

The long-term success of timber bridges depends not only on the current *technological push* lead by the Forest Service, but also on the marketplace acceptance of the concept — *the market pull.* This study will provide a better understanding of the conditions that promote and retard the acceptance of this technology. The information presented will facilitate the development of strategies to increase timber bridge adoption throughout the United States and aid in targeting the use of limited promotional and research resources.

OBJECTIVES

1. Compare selected states in terms of barriers and incentives that affect the adoption of timber in bridge systems. Identify the most important non-structural material attributes as perceived by bridge design engineers.

2. Identify the most promising market segments for timber bridges and the technology transfer and research needs in these segments.

3. Characterize the bridge material decision-making process using the Analytical Hierarchy Process, and identify the most influential attributes in the bridge purchase decision.

4. Determine current marketing practices of timber bridge manufacturers.

REVIEW OF LITERATURE

Introduction

The review of literature for this study will focus on three specific areas:

- The bridge market and the history of timber bridge adoption in the United States
- Barriers to entry of new innovations in the industrial market place
- The decision-making process, specifically the Analytical Hierarchy Process (AHP)

Because the amount of literature on each subject is extensive, only that which is most relevant to this study will be cited.

The Bridge Market

> *"There can be little doubt that in many ways the story of bridge building is the story of civilization. By it we can readily measure an important part of people's progress."*
>
> *Franklin D. Roosevelt, October 18, 1931.*

A bridge, as classified by the Federal Highway Administration, is any structure greater than 20 feet in length between abutments. This includes standard bridges, tunnels, and culverts. As of June 1988, there were 577,000 bridges classified throughout the United States. Over 230,000 of these were classified as structurally deficient (approximately 23 percent) or functionally obsolete (approximately 18 percent) (USDA 1989). A structurally deficient bridge has been restricted to light vehicles only, is closed, or requires immediate rehabilitation to remain open. A functionally obsolete bridge is one that no longer meets current criteria in regard to such things as deck geometry, load-carrying capacity, clearance, or approach roadway alignment (USDA 1989).

The total cost of replacing all existing and accruing deficient bridges through the year 2009 is estimated to be $120 billion, or $6.0 billion annually. The backlog of current deficient bridges is two-thirds of this amount, or approximately $84 billion (USDOT 1991). The Surface Transportation Act passed by the U.S. Congress authorizes over $14 billion for bridge construction over the fiscal period 1992 to 1996 (Engineering News Record 1991).

According to the Office of Transportation (USDA 1989), more than 81 percent of the 577,000 bridges in the United States are located in rural areas. Forty-six percent of these bridges are considered deficient or obsolete. The Federal Highway Administration (FHWA) defines rural areas as population centers of less than 5,000 people.

The average age of bridges in the United States is 35.5 years. Rural bridges are, on average, 36.6 years old, and urban bridges have an average age of 30.9 years. More than half of all rural bridges are less than 50 feet long; half of all urban bridges are less than 120 feet long. Forty-six percent of all bridges are controlled by state governments, and 43 percent are controlled by county governments. Counties and other local governments control 56 percent of all rural bridges. County governments are responsible for 63 percent of all rural deficient bridges and state governments are responsible for 30 percent (USDA 1989).

Deterioration of the nation's bridges is a national problem that affects rural America. Transportation accessibility, which includes time, cost, convenience, dependability, and safety, influences rural America's economic activity and development potential. With an increased dependence on trucking, inadequate roads and bridges have resulted in detours and other travel inconveniences such as slower delivery times, increased loss and damage of product, higher vehicle operating costs and, in general, less efficient transport (Brungraber et al. 1987).

The following factors are known to affect the deterioration of bridges:

- Unusually harsh climatic and environmental conditions
- Above-average traffic and truck densities
- Local design and construction practices
- De-icing chemical usage
- Maintenance policy of bridge governing unit
- Local funding availability
- Local bridge inspection procedures (Dunker and Rabbat 1990).

Other reasons for the deterioration of rural bridges include a shifting population base, the introduction of large farm machinery during the middle of the twentieth century, an abandonment of railroads which placed more burden upon local roads, an increase in allowable sizes of trucks/trailers, and a large number of older, under-designed bridges (Transportation Research Board 1983).

Ron Cheney (1986, p. 51) states:

> *"Although it is frustrating to find the same type of problems developing on bridge after bridge, it should be recognized that there are different generations of bridges that have been designed and built using the best state-of-the-art engineering and construction practices of their time. It has taken years plus the absence of sufficient maintenance programs to create the serious problems we now face. Moreover, many of these bridges were built 40 to 80 years ago, and they were not engineered to take today's loads and volumes.*

The major contributors to the overall bridge deterioration crisis are: poorly functioning expansion joints, inadequate bridge decking materials, poor drainage systems and insufficient maintenance programs."

Materials used for the main spans of bridges are classified by the National Bridge Inventory (NBI) as concrete, steel, or timber. Less than one percent are classified as other (masonry or aluminum). In urban and rural areas, concrete is used most often, followed by steel and then timber. Timber represents less than 10 percent of inventoried bridges and most often is located on rural highways (USDA 1989). Table 1 classifies bridges by type of material and location.

The four states which this study will follow in depth include Mississippi, Virginia, Washington, and Wisconsin. They are geographically located throughout the United States with differing resource bases and manufacturing climates. As Table 2 illustrates, they have differing bridge needs and adoption rates of timber bridges. Taken together, these states have close to the national average of 41 percent deficient bridges, but are above the national average of timber bridges at 11.1 percent. This is because of higher than normal rates in Mississippi and Washington. Bridge construction and maintenance responsibility varies by state. In Virginia, the state highway department controls over 97 percent of the roads, while Mississippi, Wisconsin, and Washington have local control over the rural highways.

Current Status of Timber Bridges

A recent American Society of Civil Engineering study reveals that 87 percent of timber bridges are located in 19 states (USDA 1989). Most of these bridges are located off the federal aid system and are classified as deficient. Nearly two-thirds are located in the nine states of Alabama, Arkansas, Iowa, Kansas, Louisiana, Mississippi, Nebraska, Oklahoma, and Texas. In these states, timber accounts for 20% of all bridges. There is a high concentration of timber in the central and south-central United States, which makes it a viable choice for bridge building projects in this part of the country.

Timber bridges normally serve low volume roads with 70 percent of them located on roads with an average daily traffic (ADT) count of less than 100 cars (Brungraber et al. 1987). Over 80% of the inventoried timber bridges fall under county, town, or city government jurisdiction. Fifty-five percent of these are open and un-posted for any load restrictions. The average life of these bridges is over 47 years, which is quite close to the industry's belief of 50 years. Over 27,000 of them have lasted over 50 years (Brungraber et al. 1987).

Table 3 lists the number and percentage of timber bridges by state as of 1992 according to the Federal Highway Administration (FHWA 1992). In the period from 1986 to 1992, only five states had small increases in the amount of timber bridges, all of the rest showed decreases. These five states are: Indiana, Michigan, New York, Rhode Island, and Wisconsin. It can be noted that three of these states are in the midwest, which is the home of one of the largest timber bridge manufacturers/marketing companies in the United States.

TIMBER BRIDGE ADOPTION

Background

Wood was probably the first material used to build bridges. Although this century has seen concrete and steel replace wood as the major bridge construction material, wood is still used extensively in short to medium span bridges in the United States.

Approximately 8 percent of the bridges within the National Bridge Inventory System are classified as timber. The U.S. Forest Service has nearly 7,500 timber bridges on its highway system, and the railroads have an estimated 1,500 miles of timber trestle still in use. Timber bridges have also attracted the attention of the United Nations, Canada, England, Japan, and Australia (Ritter 1990).

Muchmore (1986) lists the reasons that wood has been such a useful and versatile material through the centuries. He states:

> Structural wood.... is simple to fabricate,
> is light weight and easy to install,
> has a high strength to weight ratio insulation properties,
> has good shock resistance,
> has good fire resistance,
> is immune to de-icing chemicals,
> has unique aesthetic qualities,
> is a renewable resource, and
> is economical and long lasting, when properly protected.

The author goes on to specify the important factors in assuring long, useful lives for timber bridges: designing to avoid water-trapping joints, use of effective and compatible preservative treatment, and implementation of systematic inspection and maintenance program. Attention to these details will provide a life span competitive with other structural materials, such as steel and concrete, and will, in most cases, dramatically increase the useful life of timber bridges.

Wood can have several disadvantages as a bridge material (Ou and Weller 1985). First, since wood is a biological material, it is vulnerable to damage by fungi, fire, accidents, and insects. Second, the deeper beam sections often required when using timber may significantly reduce the hydraulic operation; reducing the flood flow capacity beneath the bridge. Third, the fabrication of glued-laminated timber members may take longer than the construction of steel beams or concrete sections. Another common complaint with timber is that it allows moisture through the deck to any steel underneath, a situation that increases corrosion.

Timber Bridge Evolution

Numerous studies have illustrated the evolution of timber bridges in the United States (e.g., ASCE 1976, Cundy 1989, Ou and Weller 1985, Ritter 1990). It is not the purpose of this section to re-introduce the history of timber bridges, but to identify the major technical innovations that have allowed the continued development of timber as a bridge material.

Timber bridges evolved in the United States out of economics and necessity. In the 18th Century, wood was the most available, abundant, workable, and least expensive resource. In 1933, Lewellyn Edwards, a civil engineer of the time, identified how innovation played an important part in the adoption of timber bridges early in our history. Edwards (ASCE 1976, p. 144) states:

> *"Transportation developments were but a challenge to those engaged in bridge building to produce structures which could be of service in spanning major waterways. In a field so fertile and inviting for inventive ingenuity, it was natural that men of special genius and self-reliance, competent to profit by their own mistakes, should direct their efforts to the development of types of structures involving the application of scientific considerations rather than the sort commonly described as "judgment founded upon error."*

The log and timber stringer bridges were undoubtedly the first adoption of wood for bridge construction. Timber trestles were next to evolve during the mid-to-late 18th century. The trestle was simply a collection of short stringer bridges. It allowed, however, the crossing of larger waterways. The early part of the 19th century saw the development of the truss and arch bridges. This introduced the use of metal connectors into timber bridge construction. The truss system allowed the use of short timbers, prefabrication into sections, and utilization of local accessible timber.

The major professional bridge builders of this time were Timothy Palmer, Louis Wernwag, Theodore Burr, and William Howe (Steinman and Watson 1941). Although each builder had a specific design, the purpose was similar – to transfer the load carrying capacity of the bridge to the abutments through the use of the truss design. It allowed for the building of timber bridge clear spans in excess of 200 feet.

The two primary problems with wood design at this time were fire and decay. It was soon discovered that keeping the wood dry could extend the service life of the bridge. Covered bridges were the next innovation in the early 19th century that assisted the adoption of timber. It is estimated that over 10,000 covered bridges were built between 1805 and 1885 (Ritter 1990). Not until the late 1800's did wood preservation become popular, and it was the early twentieth century that saw its rapid growth in the use of treated wood for bridges.

The next major technology for wood bridges began with research in the 1930's on structural glulams at the Forest Products Laboratory. With the introduction of exterior adhesives during World War II, it was not long before glulam members were replacing sawn members in bridge construction as stringers and deck members. Glulam is an assembly of individual wood laminations bonded together with structural adhesive. This allows smaller pieces to be built into virtually any size member. Glulam deck panels soon began to replace nail laminated decks on bridges across the country. Gutkowski and Williamson (1983) state the reasons for increased use of glulams. The most significant are the development of new products and manufacturing methods, improved methods of wood treating and preservatives, contemporary bridge configurations employing a systems approach, and improved analysis methods and design criteria.

Rehabilitation of existing bridge decks utilizing the concept of stress laminating of timber began with research done at the Ontario Ministry of Transportation in the early 1980's (Taylor et al. 1983). Stress laminating is a system in which steel rods are placed in the deck to compress it transversely and develop plate action within the deck. This research has led to the development of new bridge technology in the United States. The types of bridges currently being designed include pre-stressed nail-laminated and glue-laminated longitudinal decks, parallel chord truss systems, "T" sections, and box sections (Moody et al. 1990). All of these systems use small wooden members compressed in some manner with steel rods to assist in distributing load. It has allowed for the utilization of such species as red pine, red oak, red maple, and cottonwood in bridge construction. Single spans in excess of 75 feet have been designed utilizing this technology (Dickson and GangaRao 1989).

Although the product life cycle (PLC) has received the most attention in marketing literature, gradual improvement in timber bridges over the centuries support a recent idea – the product evolutionary cycle or PEC (Henderson 1989, Lambkin and Day 1989, Tellis and Crawford 1981). While the product life cycle concept is based upon birth, growth, maturity, and death, the PEC is based upon incremental improvements over past generations of products. The change in product form is cumulative, directed, motivated, and patterned.

The evolutionists state that there are five patterns of change:

1. Divergence is the beginning of a new type of product
2. Development is an increasing adaptment to meet consumer needs
3. Differentiation is to target markets or separate a product from its competitors
4. Stabilization involves few changes in product, but more changes in promotion
5. Demise is when the product no longer meets the customers' needs

Only the first and last pattern of change are in any order, the other three are not. The PEC assumes that demand is a dependent variable, and sales result from managerial actions, not from the inevitable life cycle of a product.

On the other hand, within the product life cycle, shifts in marketing strategies are the result of competitive responses. Changes within the product are necessary to meet customer needs. That is, the product life cycle is the result of a continually changing marketplace.

The PEC addressed environmental uncertainty better than the traditional product life cycle. The PEC appears to be better suited for the analysis of product development, proliferation, and management (Rao and Evers 1991). The gradual improvement of timber bridges from the log stringer to the current prestressed systems reflects the product evolutionary cycle quite well. As timber is engineered into larger and more complex bridge systems, marketing of these bridges must keep pace with the changes. Decision makers must be kept aware of the current status of the new bridge systems.

The new timber bridge systems now compete directly with steel and concrete. No longer are timber bridges just a cheaper alternative for low volume roads, but they are now a true competitor with steel and concrete. Marketing is no longer only between one timber bridge company and another, but between competing materials as well. As timber bridge manufacturers try to expand their market into more traditional bridge areas, these manufacturers will face increasing competition. Understanding how to market new bridge systems during this evolutionary change is vitally important to ensure continued success.

A comprehensive study was conducted by Luppold (1990) of ten southern states on the use of timber bridges. He states that the largest potential for timber bridges is in states with the greatest county control and where the cost of concrete exceeds $50 to $60 per square foot of bridge surface area. His recommendations to the Southern Pine Marketing Council were:

1. Be active in every state bridge committee organization.
2. Assist committees in locating interested engineers in timber bridges.
3. Understand that each state must be approached differently on the promotion of timber bridges.
4. Continue important research on bridge data throughout the United States.
5. Understand the county aid section in each state.
6. Assist in developing a maintenance program in each state.
7. The high cost of USFS demonstration bridges has been a deterrent in the adoption process.
8. Timber experts must be able to prove the longevity of these new bridges.
9. Work must be done on timber bridges to reduce maintenance.
10. Continue to monitor the testing of bridges.

11. The timber industry must do a better job of identifying the decision makers and key purchasers for timber bridges. These may include engineers, architects, contractors, or key developers.
12. Work toward developing standardized bridge plans.
13. Do a better job of promotion of southern yellow pine timbers for bridge construction.
14. Establish an awards program for highway departments using timber bridges.
15. Insure that wood engineering sections are being adequately presented to AASHTO and FHWA.
16. Encourage continued research on chemicals for wood treating and proper fabrication.
17. Determine educational needs of decision makers and perform this function as necessary.
18. Develop case histories of successful timber bridge utilization.

Current Perceptions of Timber Bridges

Although timber has a long and important history in bridge construction, it is decreasing rapidly as a primary material. In 1982, the National Bridge Inventory listed over 70,000 bridges with a main span of timber. A recent personal communication with the FHWA (1992) indicated that in 1992 there are less than 46,000 timber bridges. This represents a decline of over 33% in ten years. Figure 1 illustrates this trend.

There is no reason to believe this trend will not change unless current negative perceptions can be identified and strategies developed to overcome them. Some common perceptions of timber include:

- Too expensive
- short lived
- high maintenance costs
- potential fire danger
- not as durable as steel and concrete
- wood preservatives are dangerous to the environment
- difficult to keep a wearing surface on timber deck
- does not hold up with high traffic volumes and large impact loads (Ou and Weller 1985, Cundy 1989, Clapp 1990)

Cundy (1989, p. 6) states a common feeling among trained engineers:

> *In the present day, not everyone agrees that timber is a good bridge material. In Vermont, experience has shown reinforced concrete is more durable than timber in short spans (Warren B. Tripp, Vermont Agency of Transportation, VAT, personal communication of February 16,1989). Using such technological improvements as sheet membrane waterproofing and epoxy rebar, VAT expects a service life of 60 to 75 years from steel and concrete deck bridges and over 75 years for concrete slab structures. In high traffic volume, high load situations, prevailing opinion is that steel beams with concrete decks are the preferred material. Experience has shown timber decks to be poor performers where traffic is heavy and large impact loads are frequent.*

One of the best explanations of the decline of timber in bridge construction is provided by Ken Johnson (1990, p.6) of Wheeler Consolidated, a leading timber bridge marketer and manufacturer.

> *"The choice of bridge material is, without doubt, the most important decision the bridge design engineer will make in designing a bridge. This decision will have long-term consequences for the owner of the structure. Unfortunately, this decision is sometimes made without the benefit of good information and is sometimes the product of prejudice which has no place in professional engineering.*
>
> *The practice of engineering, as it has evolved over the years, has been shaped by the persuasive efforts of the steel and concrete industries. This persuasion has been beneficial in some ways, because the industries produced and distributed good technical information about the design and use of their products. In fact, many engineering schools use industry-produced textbooks in their curriculums. This has led to an increased reliance on the use of concrete and steel and to a corresponding decline in the use of construction materials from other industries which have not provided the same levels of technical information.*
>
> *The timber industry is one of the industries that has not made a substantial effort to generate and distribute technical information. This has been interpreted by some engineers as a reflection on the suitability of the material itself and not as an indictment of the industry for failing to provide the information. The reason the timber industry has not met the challenge becomes obvious when the different industries are compared.*
>
> *The methods by which basic materials are produced provide the answer to the question of why steel and cement industries provide technical information and why the timber industry does not. The basic difference between steel/cement producers and the timber producers is the ability of steel and cement to form single industry-wide institutions to do the necessary research and to publish the results. This is possible because of the relatively small number of companies actually producing the product. The production of only three steel companies accounts for about ninety percent of the steel produced in the United States. The number of companies producing cement is somewhat larger, but still relatively small when compared to the timber industry.*
>
> *The timber industry, by contrast, consists of a multiplicity of sawmills, both large and small, resource based companies, and many other independent operations such as treating plants. Production is then further diversified by different species. Each of these entities is fiercely independent. The task of organizing all of these independent operations is akin to trying to organize all the farmers. However, the fact that the farmers do not have a single voice does not mean that their choice beef and durum wheat are any less acceptable as steaks and bread. In the same way, the fact that the timber industry is not as unified as the concrete and steel industries does not mean that timber is not a valuable construction material."*

In an informal study of timber bridges in the Pacific Northwest, Clapp (1990) identified concerns of engineers. He found that past perceptions of timber bridges were not positive, and although in some counties as much as 60% of county bridges were timber, they were replacing them in less than 40 years. Engineers did not think timber was cost competitive, and longer spans (greater than 60 feet) were being utilized more, which reduced the use of timber. In short spans (less than 20 feet), engineers utilized metal culverts, and counties did not prefer to use their road crews to build bridges. De-icing chemicals were not a factor in the Pacific Northwest. Most counties did not have design engineers on staff, and most counties were interested in training on repair and rehabilitation of existing timber structures. Clapp (1990) concluded that if timber is to be accepted, life cycle costs and performance guarantees must be made available.

It can be seen that perceptions of design engineers have been molded by effective marketing efforts by the steel and concrete industries. From early in the engineer's training, exposure to the benefits of concrete and steel help determine the bridge material choice later in their careers. Only through effective marketing efforts can the timber industry hope to change these perceptions.

The Industrial Innovation Process and Barriers to Entry

> *"The innovator has for enemies all who have done well under the old, and lukewarm defenders in those who may do well under the new."*
>
> *Machiavelli, 1513*

No study of barriers of entry for new products can be attempted without first a discussion on innovation, diffusion, and the adoption process of new products. The literature on both these subjects is extensive, and this review will be kept to that which is applicable to this work. This study will consider the product's barriers to entry as anything that inhibits its acceptance within the marketplace setting. These factors include, but are not limited to:

- perceptions
- cost
- competing or substitute products
- past experience
- technological awareness
- demand
- promotional activities

Innovation

An innovation has been defined as any idea, object, or practice which is perceived as new by an individual or other adoption unit (Rogers 1983). The literature on adoption and diffusion of innovations has received extensive attention over the past decades (Cohn 1980, Cooper and Kleinschmidt 1987, Day and Herbig 1990, Fliegel and Kivlin 1966, Kennedy 1983, More 1986, Ozanne and Churchill 1971, Porter 1985, Rogers 1983, Rogers and Shoemaker 1971, Ryan and Gross 1943, Sheth and Ram 1987, Shama 1982, and others). Day and Herbig (1990) indicate that the industrial adoption process is exceedingly complex. Almost without exception, the buying and selling units in industrial marketing are organizations represented by several different individuals. Decision making is typically done in groups, by people with vested interests that are threatened by change, and consideration of these changes increase their perceived risk. This is quite similar to the government bodies that will purchase the timber bridge. There are normally officials from the local area, consulting engineers, and state highway officials that all must come together and agree on a bridge type.

O'Connor et al. (1990) state that resistance to technological changes by end users is to be expected and is a valuable source of information. This information is critical to successful implementation and/or marketing of the innovation. Part of the problem is that final users may not perceive the benefits or the risks of the innovation in the same way as the key decision makers and planners (Beals 1968). Many authors have indicated the need for greater attention to resistance or rejection as a response to innovation (Sheth 1981 and Sheth and Ram 1987). One goal of this study is to identify reasons for resistance to timber bridge innovation. Factors such as educational training, organizational structure, geographic location, and exposure to marketing efforts will all be considered. Sheth (1981) has stated that the concept of innovation resistance is the "less developed concept" in diffusion research. In a study by Ellen, Bearden, and Sharma (1991), they concluded that a person's perceived ability to use a product successfully affects their evaluative and behavioral response to the product. In addition, the level of satisfaction experienced with an existing behavior increases resistance and reduces the likelihood of adopting an alternative.

Robertson, as quoted in Baker (1975), has proposed that innovations should be classified by the extent of the change in behavioral patterns which their adoption necessitates. This has been identified as the product-oriented approach. Robertson identifies three types of innovations as continuous, dynamically continuous, and discontinuous.

1. *Continuous* innovation has the least disrupting influence on the established patterns. Alteration of a product is involved, rather than the establishment of a new product.
2. *Dynamically continuous* innovation has more disrupting effects than a continuous innovation, although it still does not generally alter established patterns. It may involve the creation of a new product or the alteration of an existing product.
3. *Discontinuous* innovation involves the establishment of new behavior patterns.

The timber bridge market for the decision makers would be going through a dynamically continuous innovation process. Most engineers are familiar with timber bridges, but the current advancements are certainly disruptive. Although for some it may be an establishment of new behavioral patterns and classified as a discontinuous innovation.

The innovation development process consists of all the decisions, activities, and their impacts that occur from the recognition of a need or problem, through research, development, and commercialization of an innovation, through the diffusion and adoption of the innovation by users to its consequences (Rogers 1983). It includes six main areas:

1. Needs/Problem
2. Research, basic and applied
3. Development
4. Commercialization
5. Diffusion and adoption
6. Consequences

The timber bridge innovation process can be seen in this description. The needs/problem of the infrastructure for bridge replacement was identified in the 1980's. Since that time basic and applied research have been developed to utilize wood in bridge construction. One of the goals of this research is to assist in the diffusion and adoption processes of innovation development.

Diffusion

Rogers (1983) describes *diffusion* as the process by which an innovation is communicated through channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas. Rogers and Shoemaker (1971) identify seven major diffusion research areas; anthropology, early sociology, rural sociology, education, medical sociology, communication, and marketing. Kelly and Kranzberg (Rogers 1983) reduced these into three areas by categorizing technological innovations as economic, social-psychological, and geographical. They state that the area of geography relates to spatial diffusion or the adopter's relative position in physical space. Griliche (1957) described the economist's view in his research on seed corn adoption. He states that the process of diffusion and the rate it is adopted is largely guided by payoff.

Mansfield (1966) identified four factors that affect the rate of industrial diffusion. They include:

1. The extent of the uncertainty associated with the innovation
2. The extent of the economic advantage
3. The extent of the commitment required to try the innovation
4. The rate at which the initial uncertainty regarding the innovation can be reduced

Rogers (1983) and Mansfield (1966) both identified *complexity* as a negative influence on the rate of adoption. Mansfield identified two other areas of uncertainty. He classified these areas as observable results and innovations which are consistent with existing ideas and practices. These areas seem to spread more quickly. Rogers (1983) agrees that *observability and compatibility* are positively correlated with the rate of adoption.

The attitudes and behaviors of individuals are identified in the social and psychological area. A new idea or product must be in agreement with the norms or values of the social system, and the adopter must see some personal advantage before he or she will use it (Mansfield 1966). Rogers and Shoemaker (1971) state that the members of a social system must see a relative advantage to a new product, and this is directly related to its rate of adoption.

Psychological and economic barriers of entry exist in the timber bridge adoption process. Geographically, the timber bridge has been utilized much more successfully in the Mississippi Valley region of the United States than either the West or East coast. By having a better understanding of why it has been successful in the mid-portion of our country, methods can be adopted to further timber bridges throughout the United States.

Rogers and Shoemaker (1971) have identified five characteristics of innovations that have a large influence on the rate, degree of diffusion, and adoption. The following list indicates how these five characteristics can be identified with the current timber bridge market.

1. *Relative Advantage* is the degree in which the innovation is more beneficial than the idea or method currently in practice. The timber bridge is quicker to install, may last longer, is not affected by road salts, and is economically competitive. All these features could be classified as a relative advantage of timber over competing products.
2. *Compatibility* is the degree in which an innovation is consistent with the attitudes, beliefs, and needs of the potential adopters. The current slow adoption of timber suggests that decision makers, often trained in concrete and steel, do not feel timber bridges are compatible with their attitudes or beliefs.

3. *Complexity* is the relative ease with which an innovation can be understood and implemented. The easier something is understood, the quicker it will be adopted. The current technology on the pre-stressing of timber may be complex to the engineer untrained in wood engineering. However, since the Timber Bridge Initiative (TBI) has begun, workshops all over this country have attempted to train current decision makers on this technology.
4. *Trialability* is the extent to which the innovation can be implemented a little at a time. The innovation that is trialable shows less uncertainty to the adopters, because it is possible to learn by doing (Rogers 1983). The TBI has given the economic incentive for bridge engineers to try timber bridges on a limited basis. By reducing the economic risk, engineers can observe experimental bridges in service, which will ultimately reduce the uncertainty of this new technology.
5. *Observability* is the ease in which an innovation or its effect can be seen. Any delays or lack of visible results will impede the adoption process. Although timber has been utilized over the centuries, the immediate results of the new technology are difficult to be seen. The timber engineers feel that the new bridges will last 60-75 years. It is very difficult to convince current bridge engineers of this, especially when they are replacing 35- to 50-year-old timber bridges with steel or concrete.

In the numerous definitions of the diffusion process, five elements are common:

1. The innovation
2. The adopting unit
3. The communication network
4. The acceptance process
5. The time element

In this study, the innovation will be the utilization of timber into rural highway bridges. The adopting unit will be highway decision makers at the local, county, or state level. The communication network will be the current Timber Bridge Initiative, marketing efforts by manufacturers, and informal networks that assist in the spread of this technology. The acceptance process is the timber bridge adoption rate in the selected states. The time element is from the initial start of the current *technological push* in the early 1980's to the present.

The adopting unit is the individual or group that participates in the decision-making process regarding the adoption of an innovation. Shama (1982) indicates that the greater the number of people composing the adopting unit, the more diverse are their motivations and needs and the slower the adoption process. Depending upon the individual's motivation, background, and perception of the attributes of the innovation, different individuals go through the adoption process at various rates. Rogers and Shoemaker (1971) have classified these individuals into five adopter categories.

1. I*nnovators* - represent the first 2.5% of the people to try an innovation. They are considered venturesome, risk takers, cosmopolitan, and they communicate more outside their social system. They tend to be younger, higher in economic status, better educated, and prefer impersonal communication. For the timber bridge market this would indicate that newer engineers should be more receptive to timber than those trained 20 to 30 years ago.

2. *Early adopters* - represent the next 13.5% to adopt an innovation. They are normally considered opinion leaders that are high in education and economic status. Once they adopt an innovation, others will soon follow. They are willing to take risks, but are concerned about failure. This would support the belief that the identification of the leading design engineers in each state would have a strong influence on what material would be used in bridges.

3. *Early majority* - it represents the next 34% to adopt an innovation. They have a local perspective and interact frequently with peers to draw on their experience and knowledge. They will not normally adopt until the innovation has been proven successful somewhere else. Normally, they are average in economic, education, and social status. Providing information to these people on timber bridges will hopefully stimulate an interest, and lead to discussion with peers in the early adopter category.

4. *Late majority* - These people represent the next 34% of people to adopt an innovation. They are extremely cautious and avoid innovations unless put under social or economic pressure. They tend to go along with the crowd. The late majority are normally older, below average in education, income, and social status. Not until timber bridges are accepted throughout the country can it be expected that these people will adopt.

5. *Laggards* - These traditional people represent the last 16% to adopt. They are most local in their perspective and seldom venture out of their social system. They are suspicious of innovations and their adopters. Normally of low social status and income, they adopt under reluctance. The timber bridge adoption process will be complete before these individuals try the concept.

Figure 2 illustrates this relationship graphically. Social scientists have found that this diffusion follows a normal bell shaped curve, but that these percentages are arbitrary and not absolute. Muth and Hendee (1980) have stated that the process cannot be controlled after the opinion leaders have been induced to try the innovation. These leaders will transmit their opinion to their peers in the social system. If this opinion is negative, the innovation is dead for the time being. It is vital that the innovation is ready for trial before promoting it.

Personal contact is the most important channel of communication for transfer of information critical to innovation (Rothwell and Robertson 1973). Studies by Allen (1977) and Angell et al. (1985) indicate that scientists and engineers access information by entirely different communication channels. Scientists use more academic journals; engineers utilize personal contacts to a greater extent. This information should assist in the development of strategies in dealing with engineers on timber bridges.

An important element in the diffusion/adoption process is time. It took ten years for hybrid seed corn to approach complete adoption in Iowa (Ryan and Gross 1943). The national forests took over ten years to adopt the national fire danger rating system (Muth and Hendee 1980). According to Katz et al. (1963), time is important because it allows the researcher to identify the characteristics of early adopting individuals and to establish the direction of the flow of influence. One of the primary goals of this study is to assist in identifying similar characteristics of adopting individuals and further influence adoption of timber bridges by the development of marketing strategies.

Time is involved in diffusion by the following mechanisms (Rogers 1983):

- In the innovation-decision process by which an individual passes from knowledge to acceptance or rejection of the innovation
- In the innovativeness of the adopting unit, the relative earliness/lateness with which an innovation is adopted compared with other members within the system
- In the innovation's rate of adoption in the system

Here the author defines the innovation-decision process as the stages through which an individual, or decision-making unit, passes from first knowledge of the innovation, to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, to confirmation of the idea. The five steps take time and usually occur in the sequence listed. For industrial marketing (Day and Herbig), differences in the adoption process between consumer and industrial innovations can be characterized as follows:

- The decision process almost always involves a multi-party decision-making unit.
- Adoption decisions typically involve large commitment of funds relative to individual consumers.
- Adoption involves a long-term commitment to a new innovation.
- Adoption of innovations may be viewed as unwanted disruptions.
- They tend to greatly increase levels of perceived risk.
- The impacts of acceptance of an innovation will be felt throughout the focal organization and by other surrounding organizations.

It can be seen by these classifications why the timber bridge is considered an industrial adoption process.

The two types of communication normally utilized for the diffusion of new technology are mass communication and personal contacts. Mass communication is usually used for awareness and generating interest, while personal contacts are used to influence people to try something. The flow of information is not random, but certain individuals are sought out for their opinions, suggestions, and information on new innovations (Muth and Hendee 1980). It is with these opinion leaders that effective technology transfer is communicated.

Rogers (1983) has defined communication as *"the process by which participants create and share information with one another in order to reach a mutual understanding."* The rate in which an innovation diffuses through a social system depends highly on the communication process.

Adoption

The rate of adoption is the relative speed in which an innovation is adopted or used by a social system (Rogers 1983). The best known adoption model is identified by Rogers (1962) in which five stages are classified - awareness, interest, evaluation, trial, and adoption.

1. *Awareness* - the stage during which potential adopters learn of the existence of the innovation.

2. *Interest* - the stage in which the consumer acquires information about the innovation and its functions.
3. *Evaluation* - the stage in which the potential adopter compares the new innovation with existing methods.
4. *Trial* - the stage during which the consumer may actually, but temporarily use the innovation.
5. *Adoption* - the stage during which the consumer decides full-scale use of the innovation.

The speed in which consumers go through these stages depends on their background and on the attributes of the innovation.

Ozanne and Churchill (1971) took these five stages and identified five dimensions that are involved in the industrial adoption process. They include:

- *Activation factors* - items that start the process. In modern timber bridges it would represent the current technology push by the Timber Bridge Initiative.
- *Purchase directing factors* - factors that influence the final decision. This study identifies the major factors that influence the purchase decision. This includes internal and external factors to the organization making the bridge material decision.
- *Duration from awareness to final decision.* The time required to identify the possible use of timber in the bridge design.
- *Alternatives considered* - the more complex the decision, the more alternatives considered. The factors for the bridge material decision include reinforced concrete, steel, timber, and prestressed concrete.
- *Information use* - how the decision makers utilized personal and impersonal forms of communication to make their decision.

These factors reflect the complexity of the industrial adoption process. Not only does the organization have its own culture that determines the rate of adoption, but there are numerous external factors that contribute to a new product's acceptance. The external push by government and private agencies for timber bridges has introduced an awareness and interest in some engineers. Modern timber designs are currently being evaluated and tried in many states. The success of the adoption of timber bridges will be controlled by the interaction of the external and internal influences upon the organization. It is one intent of this study to identify the influential factors in the material choice in the decision-making process.

Barriers of Entry

> *"Although technology development, adoption, and utilization have been studied in other fields, that which has been carried out in forestry is lacking empirical evidence. Lacking is information about how technologies are developed, disseminated, and what factors influence the adoption and availability of these technologies. Lacking is an understanding of the innovation system, an understanding of the barriers of implementation and the development of strategies to overcome such barriers."*
>
> *Allen Lundgren (1989)*

Barriers of entry have been defined by Porter (1980) as features of an industry that give incumbents inherent advantages over potential entrants. Shepard (1972) suggests that barriers are anything that decreases the likelihood, scope, and speed of potential competitors coming into the market. Numerous studies in management and marketing have looked at factors that identify a new product's success and failure (e.g., Booz et al. 1982, Cooper 1979 1988, Cooper and Kleinschmidt 1986, Cox 1974). It is assumed that the identification of these items will allow management to develop strategies to improve market success. Yet, estimations run as high as 80% for new product failure (Baker 1979). There are numerous examples of difficulty in introducing new products in the industrial marketplace.

Adoption of new products has been slower than expected, provided lower profit margins, required greater resources than originally planned, and in many cases resulted in withdrawal from the market (More 1986). The author continues by saying that the organizational adoption process is complex and not well understood by many managers. Therefore, many barriers to the adoption process are unseen, unanticipated, and unmanaged, with the result being rejection by potential buyers of a superior product. The real failure of managers, according to More (1986), has been the understanding and managing of the strategic relationship with the potential adopting organization. One of the primary goals of this research is to identify the factors in bridge adoption so the management of this new technology will be successful.

The study of barriers of entry has primarily been concerned with competitive responses between firms in the same market. Bain (1968) presents this competitive response in economic terms as the extent to which, in the long run, established firms can elevate their selling price above the minimum average costs of production and distribution without inducing potential entrants to enter the industry. Ferguson's (1974) economic interpretation of barriers include those factors that make entry unprofitable, while permitting established firms to set prices above marginal cost, and to persistently earn monopoly return. Porter (1980) states a marketing view in which entry barriers are defined as features of an industry that give incumbents inherent advantages over potential entrants. Shephard (1972) has a similar definition in which barriers are anything that decreases the likelihood, scope, or speed of the potential competitors into the market. In relation to the bridge market in the United States, the concrete and steel industry have created "inherent advantages" which are inhibiting successful introduction of new timber technology. This research will identify those advantages and assist the timber industry to develop methods to overcome them.

Types of Barriers

Bain (1956) identified three major barriers:

1. Economies of scale
2. Product differentiation
3. Absolute cost advantage

Porter (1980) has suggested six major barriers:

1. Cost advantage
2. Product differentiation
3. Capital requirements
4. Customer switching costs
5. Access to distribution channels
6. Government policy

Karakaya and Stahl (1991) have classified 25 market entry barriers into two categories. The first is *competitor activated or controllable barriers to entry*, which are usually generated by firms already in the market. These barriers do not always deter entry into the market, but do influence market strategies of possible entrants. The other category is classified as *environmental or uncontrollable barriers* which are generated by the nature of the market or by governmental agencies. Potential entrants can do very little to overcome these barriers.

Table 4 identifies the current manufacturer's advantages in the market place. It appears only four of these items may be related to the bridge market. They include:

1. Product differentiation and customer loyalty
2. Customer switching costs
3. Heavy advertising by incumbent firms (education of engineers is included as an advertising expense)
4. Price

The uncontrollable barriers of entry for the bridge market are:

1. Capital requirements to enter the market
2. Government licensing requirements or meeting government standards
3. Number of competitors
4. Technology and technological change
5. Seller concentration and market share held by incumbents
6. Incumbents' reaction to market entry
7. Incumbents' easy access to raw materials or possession of raw materials

In addition to supplier-controlled barriers, there are also consumer-controlled barriers that retard innovation. Sheth and Ram (1987) classified customer barriers into either functional problems or psychological resistance. Their five customer barriers include:

- *Usage* - disruption of existing work flows, practices, and habits
- *Value* - low performance to price ration
- *Risk* - waste of money, physical damage, or performance uncertainty
- *Tradition* - social norms and cultural attitude dictating usage
- *Image* - taboos, stereotyping, and negative association

All five of these barriers could be identified with the current feelings of many bridge engineers with regard to timber bridges.

Timber Bridge Barriers

The review of literature, personal experience, and discussions with experts in the field have identified five major factors to study in the adoption of timber bridges. These items may act as barriers or incentives to timber bridge adoption. They include:

- *Resources* - forest resource base, manufacturing facilities, engineering expertise, and availability of timber bridge information

- *Conditions* - bridge ownership, bridge costs by type, maintenance and funding procedures, and legal and environmental conditions
- *Demand* - age of bridges in state, number of deficient bridges, replacement strategies, and timber bridge market share
- *Familiarity* - number of demonstration bridges, previous experience with timber bridges, number of timber bridges in state, and promotional activities
- *Decision makers* - perceptions of timber bridges, decision-making structure, and who makes material decision

This study will identify these variables in selected states and determine which are most important in the adoption of timber bridges.

Government Marketing and Adoption Barriers

Barriers to the adoption process for bridges may be more complex than other innovations due to the fact that the purchase decision is being made by government bodies. Although federal, state, and local governments spend over $750 billion a year (McCarthy and Perrault 1987), there is little research on marketing or adoption by governmental bodies. Withey (1990) identified four common characteristics of government purchasing.

1. Government purchasing usually begins with official invitations to bid.
2. Government buyers choose vendors based upon a variety of criteria, not unlike the private sector.
3. One of three methods characterizes the actual awarding of the contracts.
4. Supplier activities are vigorously monitored during the life of the contract.

Withey states that "time" plays an important role in government purchasing. Purchases occur often only after long-term relationships have been established with potential suppliers. Often long lead-times precede the awarding of government contracts. Once the contracts are awarded they are often for long periods of time.

These differences are important because timber bridges are marketed to different levels of governmental bodies, all of which have input into the decision. In fact, a minimum of three different decision-making groups may be involved. At the local level a town or county highway board would be the first to decide if a bridge is to be replaced. A consulting engineer or state engineer would then be utilized to determine the best structure for the bridge site. All levels would then come together to make the best decision.

Product Success and Failure

With an understanding of why new products succeed or fail, it is possible to improve new technology's performance. In the United States, from the period of 1978 to 1986, new products' contribution to profits rose from 23% to 32% of total profits (Sarin and Kapur 1990). Although numerous studies have identified factors for success, Cooper (1990) consolidated the findings as:

1. A superior product that delivers unique benefits to the user
2. A well-defined product and project prior to the development stage
3. Quality of execution of technological activities

4. Technological synergy
5. Quality of execution of pre-development activities
6. Marketing synergy
7. Quality of execution of marketing activities
8. Market attractiveness

Cooper (1990) states that superior products with a strong market orientation are the major reasons for successful introduction. Market orientation plays a vital role in the development of the product. All too often, he states, market research is done after development to verify market acceptance. Successful products have market input into the design decisions to meet customer needs. This study will identify what the bridge design engineer wants in a product and help assist in further development of timber bridges.

Along with factors that influence success, the identification of common failure factors in new products can assist in the development of strategies to market timber bridges. In a 1964 study by the National Industrial Conference Board (NICB 1964), eight common factors for failure were identified:

1. Inadequate market analysis
2. Product defects
3. Higher costs than anticipated
4. Poor timing
5. Competitive reaction
6. Insufficient marketing effort
7. Inadequate sales force
8. Inadequate distribution

Many of these factors are market research oriented. They agree with the success factors identified by Cooper (1990), in that market research of new products is vital to their success. The importance of the alliance between technology adoption and marketing is best summed up by Kiel (1984):

> *Market pull and technology push are not opposing or mutually exclusive paths to innovation. Understanding the technology-marketing interface and integrating it with corporate strategy and organizational design is the way to maintain a productive balance between these two.*

Decision Making

> *One must learn by doing the thing, for though you think you know it - you have no certainty, until you try.*
>
> *Sophocles, 400 B.C.*

The previous sections have demonstrated that there exists a large market for bridges in the United States. The process of diffusion of innovations is complex, with many factors affecting the decision process. Although timber bridges are a structurally proven alternative to concrete and steel, their market share has dropped by over 33 percent in the past ten years. Even with the current technological push by government and industry, timber bridges have declined in 45 of the 50 states since 1986.

It is evident that there is a lack of understanding of the factors that affect the decision-making process within the unit of government that purchases bridges. Only with a thorough understanding of the material-choice decision, can further insight be developed concerning strategies to promote timber.

Decision making has been defined as a process of choosing among alternative courses of action, based upon a certain set of criteria, in order to attain a goal or set of goals (Dyer and Forman 1991). It consists of three phases once a problem has been identified: intelligence, design, and choice. Dyer and Forman (1991) state that implementation is not part of the decision-making process, but the result of it. Table 5 lists the parts of the phases in the decision-making process.

Types of decisions have been classified by Golden et al. (1989). The simplest and most efficient is the holistic approach. If you know what you want, then choose it! Another popular method of decision making is to decompose the problem into sub-components and list the pros and cons of each. A very popular method of group decision making is the *Delphi technique* in which people are asked in a questionnaire or verbally to state their preferences on a set of alternatives. The *Delphi technique* contains a feedback loop which terminates when a consensus is reached. This method starts with a questionnaire which is sent to the decision group. The results are then analyzed and this process is repeated until an agreement is reached.

Another method which has gained popularity as of late is the *Multi-Attribute Utility Theory* or MAUT. This approach requires the decision maker to answer questions dealing with probabilities of the alternatives. Based upon these probabilities, the best decision is then made. Both methods are considered *normative* because data dominate the decision criteria.

The Analytic Hierarchy Process

The method chosen for this research is the *Analytic Hierarchy Process* (AHP). It has an advantage over the previously mentioned methods because it allows the introduction of qualitative, as well as quantitative, data. It is a behavioral model, as well as a normative method of decision making. Qualitative data are important in this research because of the necessity to determine the underlying reasons for the decline of timber bridges in the United States and the slow rate of adoption of current technology. Only by asking the people who make these decisions can appropriate answers be discovered and strategies formulated to change the current patterns. Patton (1990, p. 3) states: *"Qualitative inquiry cultivates the most useful of all human capacities -- the capacity to learn from others."* Bridge decision makers have demonstrated that there exists underlying reasons that timber is not being designed into bridges in the United States. These qualitative factors must be taken into account when considering alternatives.

The *Analytical Hierarchy Process* was developed by Thomas Saaty in the early 1970's. Saaty states that the practice of decision making is concerned with weighing alternatives which fulfill a set of desired objectives. The problem is to pick the alternative which most completely fulfills the set of objectives. The AHP derives numerical weights for alternatives with respect to sub-objectives and for sub-objectives with respect to higher order objectives (Saaty 1980).

Major books on the subject include:

- *The Analytic Hierarchy Process* (Saaty 1980)
- *Decision Making for Leaders (Saaty 1982*
- *The Logic of Priorities* (Saaty and Vargas 1982)
- *Prediction, Projection and Forecasting* (Saaty and Vargas 1991)
- *An Analytic Approach to Marketing Decisions* (Dyer and Forman 1991)

The AHP has been utilized extensively in marketing and group decision-making applications. As of 1987, AHP has been utilized in at least 21 Ph.D. dissertations (Shim 1989). The following is a list of subjects that have applied the AHP to decision-making processes:

- Evaluation of route choices for expressways
- Rural economic development strategies
- Risk assessment of international investments
- Checking and evaluating military and political officers
- Determining environmental treatments for dust/toxic pollutants
- Estimation of urban travel demand
- Division of labor amongst rail marshaling yards
- Designing metal cutting tools
- Grading tea leaves with sensual assessments
- Evaluating bidders of hydroelectric projects
- Decisions on urban land use
- Choice of a design for a bridge in Pittsburgh, Pennsylvania

Although many definitions have been used to describe the fundamental principles of the AHP, perhaps one of the best has been presented by Harker and Vargas (1987, p. 1383):

> *"The AHP is a comprehensive framework which is designed to cope with the intuitive, the rational, and the irrational when we make multiobjective, multicriterion and multiactor decisions with and without uncertainty for any number of alternatives. It is a method of deriving ratio scales used to integrate our procedure for representing the elements of any problem. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and then calls for only simple pairwise comparison judgments to develop priorities in each hierarchy."*

Harker and Vargas (1987) go on to state that there are three principles which one can recognize in AHP problem solving:

1. Decomposition
2. Comparative judgments
3. Synthesis of priorities

The *decomposition* principle structures the elements of the problem into a hierarchy. *Comparative judgment* generates a matrix of pair-wise comparisons of all elements in a level with respect to each related element in the level immediately above it. By manipulating the matrix, one obtains ratio-scaled priority ratings for the set of elements compared. *Synthesis of priorities* is used to generate the global or composite priority of the elements at the lowest level of the hierarchy (Harker and Vargas 1987). Harker (1989) summarizes the four basic axioms that the AHP is based upon:

Axiom 1. Given any two alternatives (or sub-criteria) i and j out of the set of alternatives A, the decision maker is able to provide a pairwise comparison a_{ij} of these alternatives under any criterion c from the set of criteria C on a ratio scale which is reciprocal; i.e., $a_{ji} = 1 / a_{ij}$ for all i, j, ε A

Axiom 2. When comparing any two elements i, j, and A, the decision maker never judges one to be infinitely better than another under any criterion c ε C; i.e., $a_{ij} \neq \infty$ for all i, j ε A.

Axiom 3. One can formulate the decision process as a hierarchy.

Axiom 4. All criteria and alternatives which impact the given decision problem are represented by a hierarchy. That is, all the decision maker's intuition must be represented, or excluded, in terms of criteria and alternatives in the structure and be assigned priorities which are compatible with the intuition.

Saaty (1980) says that a hierarchy is a particular type of system, which is based on the assumption that the entities, which we have identified, can be grouped into disjoint sets, with the entities of one group influencing the entities of only one other group and being influenced by the entities of only one other group. The elements in each group or level of the hierarchy are assumed to be independent. He states that the basic use of a hierarchy is to seek understanding at the highest levels from interactions among the various *levels* of the hierarchy, rather than directly from the *elements* of the levels. He goes on to say that a valuable attribute of hierarchies is that although the representation of the system may differ from person to person, people usually agree on the bottom level of actions to be taken and the level above it, the characteristics of those actions.

Several advantages of the hierarchical method include (Saaty 1980):

1. Hierarchical representation of a system can be used to describe how changes in priority at upper levels affect the priority of elements in lower levels.
2. Hierarchies give great detail of information on the structure and function of a system in the lower levels and provide an overview of the actors and their purpose in the upper levels.
3. Natural systems assembled hierarchically evolve much more efficiently than those assembled as a whole.
4. Hierarchies are stable and flexible.

The four steps in solving a decision problem using the AHP include:

1. Create a decision hierarchy by breaking down the decision problem into a hierarchy of interrelated decision elements.
2. Make pairwise comparisons of decision elements.
3. Use the eigenvalue method to estimate the relative weights of decision elements.
4. Synthesize the relative weights of decision elements to arrive at a set of ratings for the decision alternatives (Johnson 1980).

The hierarchy is normally set up as goal-actors-criteria-subcriteria-alternatives, as Figure 3 illustrates.

After the hierarchy is established, the next step is to prioritize the elements at each level with respect to the level above. This process begins at the top of the hierarchy (goal) and proceeds downward to the alternatives. Priorities are developed from pairwise comparisons between elements. These comparisons are made with respect to "importance," "preference," or "likelihood," whichever is the most appropriate comparative adjective. Saaty uses a pairwise comparison scale from 1 to 9 to rate one element more important (or preferred or likely) than another element. The reader is referred to Saaty (1980) for the justification of this scale.

Table 6 illustrates the rating scale and the numerical meanings proposed by Saaty (1980). In the example of Figure 5, actor 1 would be compared with actors 2 and 3, while actor 2 would be compared with actor 3. Then the elements of each group of criteria are compared with respect to the associate actor compared with respect to each of the criteria. Again, the reader is referred to Saaty (1980) for complete explanation of the process and theoretical background. Table 7 is an example of the matrix that can be set up from the data in Figure 5.

Once all the matrices have been generated via pairwise comparisons, the next step is the computation of the vector of priorities for each matrix. In mathematical terms the principal eigenvector is computed and, when normalized, becomes the vector of priorities. Saaty (1980) describes four methods to do this. One good method is to divide the elements in each column by the sum of that column, (normalize the column), and then add the elements in each resulting row and then divide this sum by the number of elements in the row. He calls this the process of averaging over the normalized columns. For the example, the results are indicated in Table 8. From this it can be seen that criteria 1 is most important for actor 1. Similar computations are carried out for each of the matrices at each level of the hierarchy.

The final composite preference vector for the decision is the matrix product of (1) the matrix composed of the preference vectors and (2) the vector of criteria important in the decision. The overall decision is based on the criteria measured.

The Bridge Decision Problem

The decision maker's problem in this study is: "What is the best material to use in building a bridge at a given location?" The purpose of this research is to identify the factors that affect timber bridge adoption and see how they influence this decision-making process. The actors for the problem include state Department of Transportation (DOT) officials, consulting engineers, and county/ town highway officials. The initial factors identified in the problem included: cost, maintenance, aesthetics, life expectancy, local preference, time of installation, environmental concerns, risk, and employment opportunities. The alternatives in this problem were reinforced concrete, pre-stressed concrete, steel, and timber. After initial interviews with highway officials, this information was refined and a decision hierarchy made.

Summary

As this literature review has demonstrated, there exists a serious bridge problem in the United States. Timber bridges, although a viable option, continue to lose market share, even with the current Timber Bridge Initiative program. Innovation and diffusion of technology are a complex and time related process, which create many barriers to the adoption process. Industrial products, which are normally purchased by buying centers or groups, add to the complexity because of the many different people involved in the purchase decision. Only by understanding the decision-making process, can the factors that impede adoption be recognized and addressed.

A well established model to understand the multi-criteria adoption process is the Analytic Hierarchy Process developed by Thomas Saaty (1980). It allows the introduction of qualitative data, along with quantitative information, into the decision-making model. It also allows for changes in criteria ratings to demonstrate how they affect the final decision. These are the primary reasons this model is best for understanding the bridge decision process.

There has been little research on the marketing of timber bridges. The majority of studies have concentrated on the engineering applications or cost analysis, not marketplace acceptance. Little published information can be found which has tried to identify the factors that influence the adoption and diffusion of timber bridges. Only with a thorough understanding of these factors can timber bridge adoption be increased throughout the United States.

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Table 1. United States Bridges by Material Type

Location	Unit	Concrete	Steel	Timber	Other	Total
Rural	Number	235,393	176,752	53,050	2862	468,057
	Percent	50.3%	37.8%	11.3%	0.6%	100.0
Urban	Number	63,806	43,004	2076	956	109,845
	Percent	58.1%	39.2%	1.9%	0.8%	100.0
Total	Number	299,202	219,756	55,126	3818	577,902
	Percent	51.8%	38.0%	9.5%	0.7%	100.0

Note: The number of total bridges will differ because of missing values. *Source:* National Bridge Inventory, FHWA, U.S.DOT, as of Dec. 31, 1988.

Table 2. Bridge Classifications in States Included in Case Studies

State	Total Bridges[1]	Non-Deficient	Structurally Deficient	Functionally Obsolete	Total Timber Bridges[2]
Mississippi	16,994	8010	6421	2563	4026
Percentage		47.1%	37.7%	15.0%	24.0%
Virginia	12,652	8368	1607	2677	67
Percentage		66.1%	12.7%	21.1%	0.5%
Washington	6898	5037	920	941	876
Percentage		73.0%	13.3%	13.6%	13.3%
Wisconsin	12,963	7530	3978	1455	536
Percentage		58.0%	30.6%	11.2%	4.1%
Total	49,507	28,945	12,926	7636	5505
Percentage		58.4%	26.1%	15.4%	11.1%

Note: Percentages may not total to 100% do to rounding errors.

[1] *Source: USDOT 1989*

[2] *Source: FHWA 1992*

Table 3. Timber Bridges by State - 1992

STATE	NUM.	%	STATE	NUM.	%	STATE	NUM.	%
Alabama	2223	14.4	Louisiana	4371	31.9	Ohio	170	.6
Alaska	166	19.7	Maine	35	1.5	Oklahoma	2752	12
Arizona	89	1.5	Maryland	188	4.9	Oregon	879	14.2
Arkansas	2189	17.2	Massachusetts	126	2.5	Pennsylvania	291	1.3
California	927	4.1	Michigan	458	4.3	Rhode Island	29	4.1
Colorado	873	11.6	Minnesota	1968	15.2	South Carolina	391	4.4
Connecticut	37	0.9	Mississippi	4026	24.0	South Dakota	654	10.2
Delaware	36	4.7	Missouri	469	2.0	Tennessee	1021	5.4
Florida	664	6.3	Montana	1473	31.6	Texas	3560	7.7
Georgia	509	3.6	Nebraska	2626	16.9	Utah	191	7.2
Hawaii	52	5.0	Nevada	38	3.3	Vermont	84	3.2
Idaho	274	7.4	New Hampshire	123	5.4	Virginia	67	.5
Illinois	182	0.7	New Jersey	282	4.6	Washington	876	13.1
Indiana	477	2.7	New Mexico	278	7.9	West Virginia	53	.8
Iowa	3768	15.1	New York	292	1.7	Wisconsin	536	4.1
Kansas	2037	8.0	North Carolina	1619	9.9	Wyoming	275	9.6
Kentucky	207	1.6	North Dakota	773	16.4			

Note: Num — Number of timber bridges in state. % — Percentage of timber bridges in state of all bridges. *Source*: FHWA 1992

Table 4. Barriers of Entry into Industrial Markets

Competitor Activated or Controllable Barriers to Entry

1. Incumbents' cost advantages due to economies of scale
2. Incumbents' cost advantages due to experience or learning curves
3. Incumbents' absolute cost advantages
4. Incumbents' superior production processes
5. Product differentiation and customer loyalty
6. Customer switching costs
7. Access to distribution channels
8. Heavy advertising by incumbent firms
9. Research and development
10. Trade secrets held by competitors
11. Price
12. Selling expenses
13. Incumbents proprietary product technology

Environmental or Uncontrollable Barriers to Entry

1. Capital requirements to enter markets
2. Capital intensity of market
3. Government licensing requirements
4. Incumbents' government subsidies
5. Number of competitors
6. Technology and technology change
7. High profit rates earned by incumbents
8. Seller concentration and the magnitude of market shares held by incumbents
9. Sunk costs
10. Incumbents expected reaction to market entry
11. Incumbents relative easy access to raw materials
12. Possession of strategic raw materials

Source: Karakaya and Stahl 1991

Table 5. Stages of the Decision-Making Process

1. **Intelligence phase** - identify the central decision problem
    1. Perform a situation analysis
    2. Conduct search and scanning procedures
    3. Problem identification
    4. Determine problem ownership
    5. Present a problem statement

2. **Design phase** - develop alternatives and establish criteria
    1. Search for alternatives
        a. initial list
        b. revised list
    2. Set criteria for choice
        a. must criteria
        b. want criteria
    3. Predict and measure outcomes

3. **Choice phase** - evaluate alternatives
    1. Develop multicriteria decision model
    2. Solution to the model
    3. Sensitivity analysis
    4. Selection of alternatives

4. **Implementation** - Action plan and Control system

Source: Dyer and Foreman 1991

Table 6. Rating Scale for Analytic Hierarchy Process

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong importance	An activity is favored very strongly over another; its dominance demonstrated in practice.
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between adjacent scales	When compromise is needed.
Reciprocals of above non-zero	If activity *i* has one of the above nonzero numbers assigned to it when compared to activity *j*, then *j* has the reciprocal value when compared with *i*.	A reasonable assumption.
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix.

Source: Saaty 1980

Table 7. Example: Paired Comparison Matrix for AHP

Actor 1	Criteria 1	Criteria 2	Criteria 3
Criteria 1	1	5	9
Criteria 2	1/5	1	3
Criteria 3	1/9	1/3	1

Table 8. Example: Vector of Priorities Calculation for AHP

Actor 1	Criteria 1	Criteria 2	Criteria 3	Vector of Priorities
Criteria 1	.76	.79	.69	.75
Criteria 2	.15	.16	.23	.18
Criteria 3	.09	.05	.08	.07

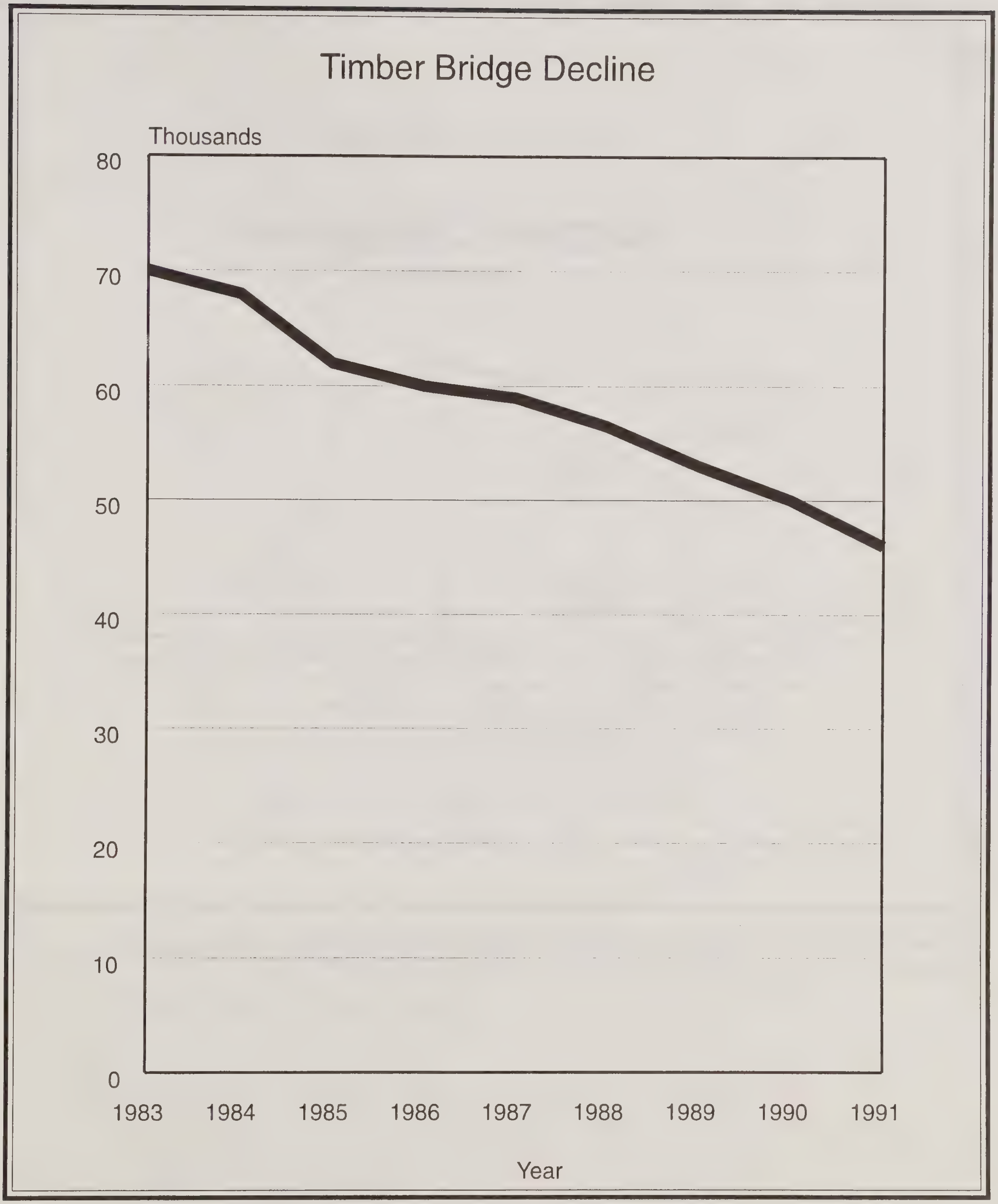

Figure 1. Decline in Timber Bridges in the U. S. from 1983 through 1991

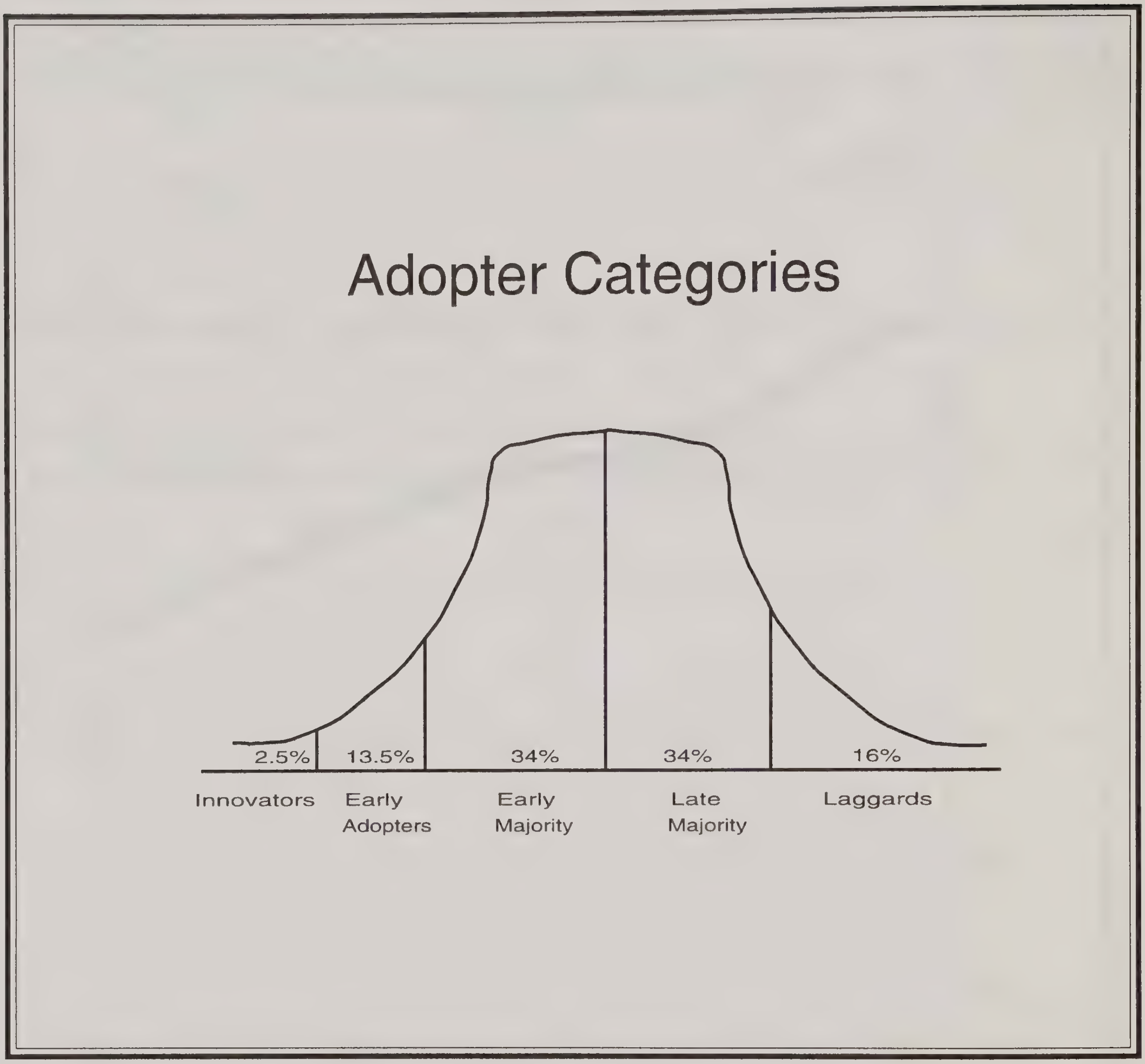

Figure 2. Adopter Categories to Innovation, (Rogers and Shoemaker 1971)

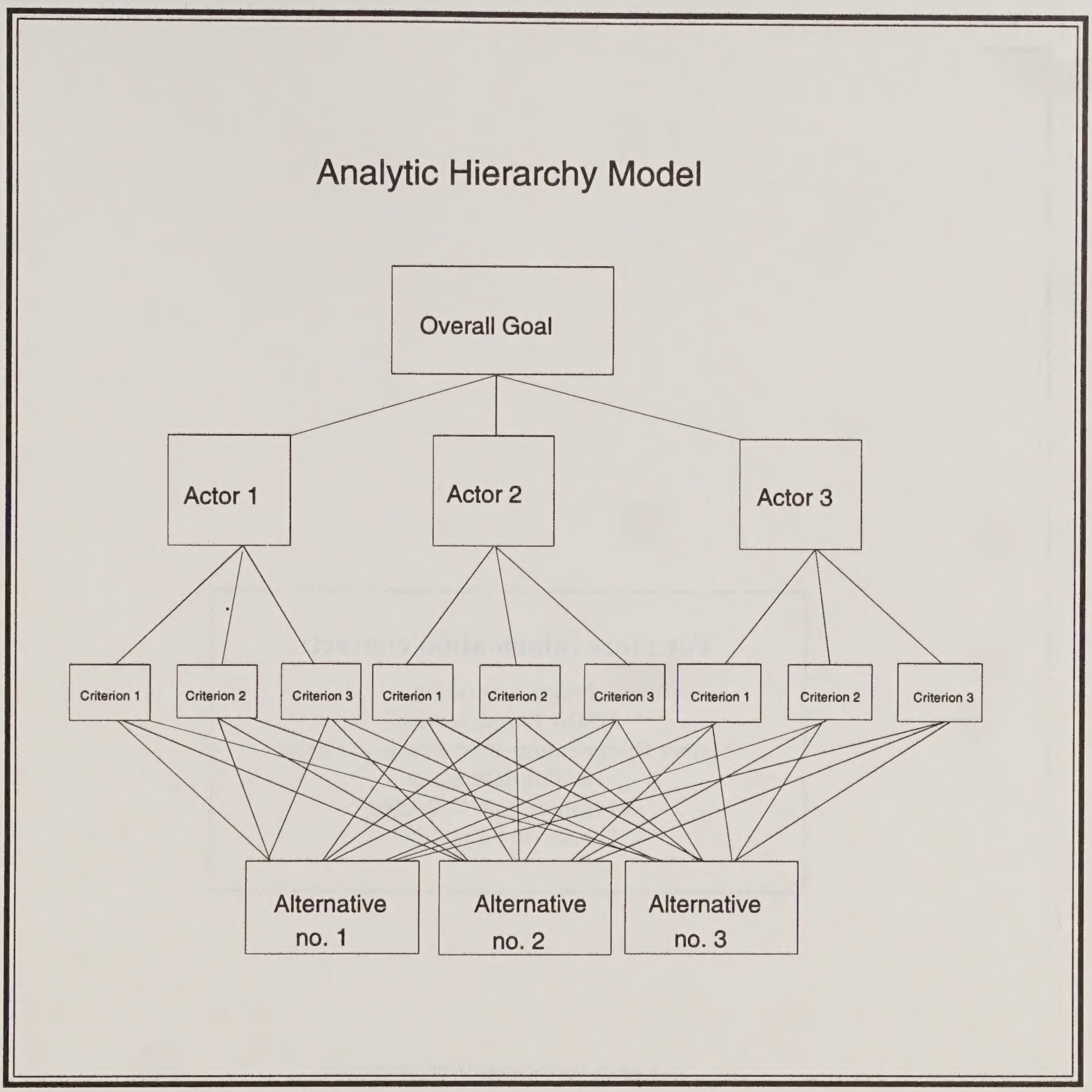

Figure 3. Example: Analytic Hierarchy Model

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